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ABSTRACT

The Los Alamos Neutron Science Center (LANSCE) provides neutrons and protons for research at three user facility areas. The 800-MeV linear accelerator, proton storage ring (PSR), beam transport systems and target areas have operated routinely at beam power levels of 1kW to 800kW and up to 1MW. The facility has been operational for 30 years and has served a diverse user community. Substantial experience has been gained in the operation, maintenance, and improvement of the linear accelerator, PSR, and beam transport systems. We will review our experience in the operation and maintenance of this facility and provide summary lessons learned for similar facilities now under design or construction.

I. INTRODUCTION

The Los Alamos Neutron Science Center (LANSCE), formerly known as the Los Alamos Meson Physics Facility (LAMPF), is a unique multidisciplinary facility for science and technology. The core of the facility is an 800-MeV linear accelerator system that is capable of accelerating up to 1MW of protons and 100kW of negative hydrogen ions, the latter with pulsed beam timing patterns suitable for a wide variety of experimental programs.

The LAMPF facility provided 800 kW of protons through two rotating graphite targets that produced secondary beams of pions and muons. After passing through these targets the beam exited the vacuum envelope, passed through targets designed to produce radioisotopes for medical applications, and then entered a water-cooled copper beam stop. The interaction of the beam with the beam stop served a materials science irradiation facility and also served as a source of neutrinos for fundamental physics measurements. Very low current polarized proton beams were also delivered to the Nucleon Physics Laboratory, and negative hydrogen ion beams were also transported to the Weapons Neutron Research facility.

The present LANSCE facility serves three experimental areas. At the Manuel Lujan Jr. Neutron Scattering Center (Lujan Center) sixteen flight paths utilize pulsed cold, thermal and epithermal neutrons produced at 20 Hz by intense 0.13 μs (FWHM) bursts of protons incident on a tungsten spallation target and moderated by water or liquid hydrogen. The Weapons Neutron Research Facility (WNR) provides the most intense source of high-energy neutrons in the world for neutron nuclear science. It uses a bare tungsten target that serves six flight paths. The Proton Radiography Facility (pRad) provides a unique facility for the study of dynamic processes using the proton beam and a magnetic lens imaging system.

II. ACCELERATOR SYSTEMS

The accelerator radio frequency (rf) systems are pulsed at a repetition rate of up to 120 Hz with a pulse length of up to 1 ms, corresponding to a macroscopic duty factor of 12 %. Present typical full-power operation is 120 Hz at rf pulse lengths of 835 μs that corresponds to an rf duty factor of 10 %. The peak beam current that can reliably be accelerated during a beam pulse is 16 mA. The average beam current capability is 1 mA at 800 MeV yielding a beam power of 800 kW. An average current of 1.25 mA at 800 MeV was accelerated for a period of 24 hours, demonstrating the capability of the accelerator to produce a beam of 1 MW average power.

The accelerator system consists of H+ and H- ion sources, each connected to a Cockcroft-Walton electrostatic pre-accelerator that provides a beam of energy 750 keV. A low energy beam transport (LEBT) system prepares the transverse and longitudinal phase-space characteristics of each beam for common injection into a 100-m long Alvarez drift-tube linear accelerator (DTL) that raises the energy from 750 keV to 100 MeV. The DTL consists of four tanks. The first tank accelerates the beam to 5 MeV, and each subsequent tank raises the energy by ~30 MeV. The drift tubes contain focusing quadrupole magnets that maintain the transverse beam characteristics. A chain of solid-state and vacuum tube amplifiers operating at 201.25 MHz provides up to 3 MW of peak power to drive each tank at resonance.

The final 700 m of the accelerator is a side-coupled cavity structure that operates at 805 MHz. The structure consists of eight 4-tank modules and thirty-six 2-tank modules, with focusing quadrupole magnet doublets between the tanks. Forty-four 805 MHz, 1.25-MW peak power klystrons excite the forty-four modules.

A beam switchyard separates and directs beams of different characteristics to the three experimental areas. The beam destined for the Lujan Center passes through the PSR where the accumulated charge is compressed into a very narrow (0.130 μs FHWM) but intense pulse that is delivered to the neutron production target.

III. OPERATIONS EXPERIENCE

The accelerator facility was commissioned and attained full design energy in June 1972. Operation at full design power was achieved some 10 years later. In the early design phase the accelerator was envisaged as a "meson factory," with a single high-power beam passing through targets to produce secondary beams of pions, muons and neutrinos. It was quickly recognized, however, that it was possible to accelerate both protons and negative hydrogen ions on the opposite phases of the rf fields in the accelerating structure. This realization led to the installation of two negative hydrogen ion sources, one of which provided a polarized proton beam. The addition of these ion sources and the necessary changes to the beam switchyard and other beam transport elements led to an accelerator facility of unprecedented flexibility and complexity.

While LAMPF/LANSCE reigned as the highest-power proton accelerator for almost two decades, the road to this position presented many challenges. One issue faced early on was proper collinear alignment of many tanks that comprise the 800-m accelerating structure. This was a critical element for success because of the desire to simultaneously accelerate the two charge species. It is not possible to use DC steering magnets to perform orbit correction for both charge species in the linear structure. As a consequence, steering is only available prior to injection into the DTL, and again prior to injection into the CCL. Precise alignment was essential to properly accelerate both charge species with sufficiently low loss as to permit hands-on maintenance.

It is important to minimize beam loss in the accelerating structures once the final alignment has been achieved. The linear accelerator has never benefited from a reliable beam position monitoring system, and it is not possible to measure beam emittance and size parameters with interceptive diagnostics during high-power operation. Monitoring and adjusting for beam losses relies on the ability to precisely measure the beam current for each beam as it passes through every accelerating module. It is highly desirable to measure average beam current losses of 1 part in 10^4. It is also important to measure in a calibrated way the secondary particle and photon fluxes generated by lost beam interacting with the accelerating structure. Both such systems required extensive development before they became sufficiently reliable tools to support operations.

Operating periods for the LAMPF/LANSCE complex have historically been divided into three to five operating "cycles." Reliability for beam operations has been recorded for each cycle by measuring the time beam above a threshold current (typically 50% of the scheduled beam current) was on to the target and then dividing this delivered time by the scheduled operating time. For the high-power H+ beam the average reliability from 1979 to 1998 for the first cycle of each operating period was approximately 80%, the average of the best cycle for each operating period was 87%, and the overall average was 83%. Beam reliabilities for H- operation were typically 7% lower than those for H+ operation. This difference is attributable to the additional complexity of the H- beam delivery systems for the Lujan Center and WNR, which include pulsed magnets, stripper foils, and the PSR. The recent beam delivery performance for the 80-100 kW beam delivered to the Lujan Center has significantly improved, with reliabilities of 92% and 86% respectively for the 2001 and 2002 operating periods. The increased reliability is attributable to improvements in kicker magnet modulators, DC power supplies, and the rf buncher drive system in the PSR.

Some design features of the DTL have also presented interesting challenges. The drift tubes themselves have several right-angle bends in the coolant flow passages, and the inlet and outlet manifold bends are adjacent to braze joints. It is necessary to carefully control the flow rates through these passages to prevent erosion of both the base copper and the brazing material. Each of the 165 drift tubes is different in size, so the flow through each is unique. In the past, errors have been made in setting the flows at too high a rate. This resulted in serious damage to drift tubes 22 and 68; passages resulting from erosion caused water leaks into the drift tube soft vacuum. These two drift tubes were successfully replaced in 1995 and 1996 respectively after approximately 25 years in service. At the same time the flows through all the drift tubes were reversed in an effort to mitigate further erosion. A similar erosion phenomenon has occurred in the CCL, with leaks developing at bends in 0.375-inch diameter copper tubing cooling loops that are brazed into the end plates of the tanks. These leaks also began to occur after about 25 years of system service. These leaks have been repaired in-situ with epoxy sealant.

In the mid-1990's all elbows and T-connections in the underground cooling-tower piping distribution were replaced because of corrosion that resulted from improper lagging during installation. Service lifetime was again about 25 years.

Early in 2003 serious flow blockage problems were identified in the steel tank-wall and copper post-coupler systems associated with the DTL. In the case of the steel system significant deposits of magnetite were identified. In the case of the copper post-coupler system, the deposits were copper oxide and cupric hydroxide. The systems were flushed with acid solutions to remove the deposits, and then neutralized and passivated. It is important to install water systems according to appropriate standards, to set and maintain flow rates according to engineering design requirements, and to maintain proper water chemistry. These obvious steps, which are often set aside during personnel transitions and times of tight budgets, can ensure indefinite system lifetime.

There was a significant drop in accelerator reliability from 1989 through 1992. Reliability for different cycles ranged from 60% to 80% during this period. This reduction was caused by a much-increased rate of failure of the Burle 7835 vacuum triode tubes that are used as final power amplifiers for Modules 2-4 in the DTL. These failures were attributable to several factors, including changes to the manufacturing process, loss of key personnel coupled with insufficient turn-over of critical operating knowledge to new personnel, inadequate documentation of operating practices, and inadequate instrumentation to properly measure the plate dissipation within the tube. Mitigation of this problem centered on hiring two engineers and providing them with sufficient time and resources to understand and correct the deficiencies.

The PSR presented a different set of challenges. The accelerator and high-power target area had reached full maturity when the PSR was added, so it was not necessary to simultaneously commission the accelerator and PSR. Several unique challenges have been resolved over the years, including the transition from neutral beam to direct H- injection, understanding of first-turn losses, addition of active safety system instrumentation to mitigate errant beam conditions, stripping foil lifetime improvements, and taming of the electron-proton instability.

Recent categorization of the Lujan Center target as a Department of Energy Category-3 Nuclear Facility has significantly changed the level of formality of operations at LANSCE. Complex authorization basis documents that incorporate detailed hazard and accident analyses have been and continue to be developed. Paramount among the accident analyses is the postulated loss-of-coolant accident in concert with failure of all beam shut-off systems. Analyses underway at this time seek to reduce the airborne release fraction (ARF) for this scenario, therefore allowing a longer target irradiation time before a costly replacement is required. Configuration management and training is an important element of successful operation of both the nuclear facility and the accelerator complex. To support this operational discipline, the LANSCE facility has been one of the leaders in implementation of Conduct of Operations at Los Alamos National Laboratory.

IV. MAINTENANCE EXPERIENCE

The reactive/corrective approach to maintenance at the LAMPF/LANSCE facility has had mixed success. Implicit in this approach has been a philosophy that the majority of the fiscal resources should be focused on the scientific output of the facility. This philosophy was adopted in about 1978, and as a result the facility confronts, at the present time, a significant backlog of maintenance and equipment replacement activities.

Day-to-day maintenance activities are handled through an internally developed Web-based Maintenance Request and Tracking System. On-shift operating personnel can submit non-urgent requests for maintenance using this tool, and the requests are sent by electronic mail to the responsible maintenance personnel who update the database to indicate progress with or closure of requests. The response to these requests is tracked and analyzed for management action on an annual basis. Maintenance support for equipment failures that compromise beam delivery is provided by continuous on-call support for all critical systems. Such support is always available for the 8-month operating periods, and response is expected within one hour of contact.

Prior to 1992 the annual accelerator turn-on process was used to ensure the readiness of equipment to operate. Corrective maintenance was performed as needed during the turn-on process. Certain routine maintenance activities were always performed during annual beam outages that were several months in length, but the work was not always fully coordinated. Resources were applied to areas that had demonstrated the lowest reliability during the previous operating period.

LANSCE has adopted a more formalized approach to maintenance management for the last three annual accelerator outages. Key components for success include the appointment of an Outage Manager, and development of an integrated, resource-loaded schedule for approximately 2000 maintenance activities and upgrade projects. Typical outages last 3-4 months with single-shift staffing. The schedules are updated weekly by maintenance team leaders, weekly coordination meetings are held, and project management support is provided. This approach has improved work coordination throughout the facility during these outages.

A new approach to readiness for accelerator turn-on that used Equipment Readiness Checklists (ERC) was instituted in 1992. This approach requires individual maintenance teams to test and certify their equipment in a staged sequence choreographed with the accelerator turn-on schedule. Ten years of experience with this manpower-intensive process has demonstrated that, while system readiness for turn-on is improved, there has been no major gain in overall system availability.

This experience, together with proposed changes to the operating schedule that address changing customer requirements, has caused LANSCE to begin an evaluation of approaches to maintenance that will improve reliability, reduce costs, and accommodate more flexible operating schedules. It is anticipated that the modifications to the process that remain to be chosen, but will focus on predictive and preventive maintenance, will be implemented in 2004.

V. SUMMARY

LANSCE has learned valuable lessons over three decades of high-power accelerator facility operation.

- Exercise strong discipline in operations from the outset by implementing the precepts of Conduct of Operations appropriately.
- Expect the unexpected during commissioning and operations.
- Maintain a strong partnership between accelerator technology and operations to ensure long-term viability.
- Implement a vigorous, planned investment in accelerator and support technology.
- Invest in the quality of staff hired to support operations. Both good people and good practices are essential to success.
- Foster collaboration and cooperation between operations and experimental support staff.
- Establish and implement sound maintenance practices at the outset, especially tracking and trending in support of predictive and preventive maintenance.

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